CARCASS TRAITS OF CROSSBRED STEERS AFTER VACCINATION AND BOVINE VIRAL DIARRHEA VIRUS CHALLENGE AS YEARLINGS

A Thesis

by

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ABSTRACT

Bovine Viral Diarrhea Virus (BVDV) is a component of bovine respiratory disease complex, which has been reported to cause the largest loss in productivity in feedlot cattle in the U.S., with annual economic losses in excess of $1.5 billion USD. The genetic influences and losses associated with BVDV challenge on carcass traits in controlled herds are not documented. This study evaluated individual animal effects in the first 14 days following challenge with BVDV Type 1b for carcass trait differences.

Nellore-Angus (*Bos indicus-Bos taurus*) F_2 and F_3 crossbred steers (n = 363) were evaluated for clinical symptoms, body weights, and rectal temperatures immediately following challenge. Crosses and sire lines were balanced across the vaccine treatment groups of non-vaccinated control (NON), killed virus vaccinated (KV), or modified-live virus vaccinated (MLV).

Hot carcass weight (HCW), adjusted fat thickness (AFT), longissimus muscle area (REA), and marbling score (MARB) were analyzed through mixed models with sire and pen(year) as random effects; fixed effects of vaccine, type of cross, pyrexia status (rectal temperature >40° C at least once), clinical symptom presentation, and levels of feed intake and ADG 14 d post-challenge were investigated. Vaccine influenced AFT (P = 0.016), where MLV steers had 0.26 cm less fat than KV steers. Marbling was affected by type of cross (P = 0.023) with up to 0.60 marbling scores higher (P < 0.05) in some parental combinations; an interaction between type of cross and pyrexia status also affected MARB (P = 0.017), with one parental combination having higher MARB associated with pyrexia. HCW was not affected by pyrexia, but was affected by feed intake (P = 0.019), with steers in the highest vs. lowest category averaging 24.0 kg heavier. No animals presented morbidity symptoms severe enough to warrant potential therapeutic treatment, animals with mild clinical symptoms in the 14 d window post BVDV challenge had 4.98 cm^2 lower REA (P = 0.012). This study affirms the complexity of health impacts on beef carcass traits and the need for study of subclinical illness in beef production systems, particularly regarding BVDV.

CONTRIBUTORS AND FUNDING SOURCES

Contributors

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INTRODUCTION

Bovine Respiratory Disease Complex (BRDC) is the largest cause of morbidity and mortality in the feedlot environment annually. BRDC is multifactorial, and used to describe illness from the group of viral and bacterial pathogens associated with respiratory symptoms, including Bovine Viral Diarrhea Virus (BVDV), which this study will focus on. This virus manifests as the illness known as bovine viral diarrhea (BVD). While not all BVD cases are detected due to subclinical illness, clinically ill animals can be detected through common symptoms that include pyrexia (fever), nasal and ocular discharge, and decreased performance (Zoetis, 2018). The majority of cases of BVD/BRD will be diagnosed early in the feeding period (Smith, 1998; Sanderson et al., 2008), when cattle are experiencing high levels of stress due to transport, transition to new diets, and animal processing events following feedlot arrival. This leads to the need to evaluate and identify novel ways to diagnose animals earlier, before animal well-being is compromised, and losses associated with morbidity occur.

Bovine Viral Diarrhea is immunosuppressive, and often leads to comorbidity with the bacterial pathogens associated with BRD (APHIS, 2007). While infection with BRD typically does not cause mortality, in all cases, it poses a significant risk of loss of overall animal well-being, as well as production and economic losses (McNeill, 1999). Even though the majority of feedlots utilize at least one respiratory vaccine to combat BRD (USDA, 2011), the average incidence of BRDC remains at 16.2% (Neibergs et al., 2014). Regardless of number of animals treated for BRD clinical symptoms across studies, it has been noted that many animals are subclinically ill, and only diagnosed after slaughter by the presence of lung lesions, produced through comorbidity with bacterial pathogens (Gardner et al., 1999; Snowder et al., 2005; Schneider et al., 2009; Griffin, 2014), leading to a large variation in rates of morbidity among literature reports. Other sources of variation in rates of morbidity include age of dam, vaccine protocol, and individual animal genetics (Schunicht et al., 2003; Snowder et al., 2005; Snowder et al., 2006; Ridpath et al., 2007; Da Silva et al., 2016)

Morbidity events during the feeding period influence feeding behavior and carcass merit, showing that feeding behavior may be an indicator of an animal's compromised health status, even if that animal is not presenting clinical symptoms. Animals experiencing illness associated with BRD have been shown to have fewer bunk visits, lower intake, lower average daily gain (ADG), and increased feed cost associated with greater days on feed (Sowell et al., 1999; Kayser and Hill, 2013; Smith et al., 2017). These in turn lead to lower marbling scores, lower carcass weights, and lower ribeye areas associated with BRD morbidity (Reinhardt et al., 2012; Waggoner et al., 2007; Runyan et al., 2014; Gardner et al., 1999), which translates to the relationship that morbid animals can not only have higher production costs associated with higher medicine costs, they can also have lower carcass value (McNeill, 1999). Therefore, if an animal becomes morbid, it is likely that feeding behavior will be negatively impacted, which can then lead to poorer carcass outcomes.

The hypothesis for the present study, then, is that morbidity early in the feeding period, will influence traditional carcass measurements (Gardner et al., 1999; Waggoner et al., 2007; Reinhardt et al., 2012; Runyan et al., 2014). Therefore, the objectives for this study were to utlize a BVDV standardized challenge model and: (1) evaluate the effect of average daily gain and dry matter intake immediately after BVDV exposure on traditional carcass measurements, (2) utilize individual animal information such as breed composition and age of dam to explain variation among carcass measurements, (3) investigate the effect of BRD vaccine protocol and traditional health response measurements such as presence of clinical symptoms and pyrexia following BVDV exposure on carcass outcomes, and (4) evaluate possible relationships among the variables of lung scores, clinical symptoms, average daily gain classification, intake classification, and animal temperament classification regarding responses to BVDV exposure.

LITERATURE REVIEW

Animal Response to Bovine Respiratory Disease Pathogens

Even though Bovine Respiratory Disease Complex (BRDC) is credited with being the largest reported loss of productivity in feedlot animals, this complex is made up of many illnesses. One of the most prevalent of these is Bovine Viral Diarrhea (BVD), which is caused by the Bovine Viral Diarrhea Virus (BVDV). While BVDV causes varied immune reactions, due to variation in host susceptibility and the virulence of the particular strain in question. Clinical symptoms may include fever, nasal and ocular discharge, and diarrhea (Zoetis, 2018). There are multiple variants of BVDV, with viruses falling into two subtypes, either BVDV subtype 1 or subtype 2, and being further classified as cytopathogenic or noncytopathogenic, with many individual genotypes within each of these categories, based on cell culture characteristics in vitro (Brodersen, 2014). This virus is immunosuppressive, and interacts with both innate and adaptive immunity. In acute infections, viremia typically resolves within 15 days, following a 5 to 7 day incubation period (Baker, 1995). Severe illness from BRD can also cause lung lesions (Wittum et al., 1996), which are associated with lower average daily gain, lower hot carcass weight, less internal fat, and lower marbling scores (Gardner et al., 1999).

Even though there are two subtypes of BVDV, type 1 and type 2, with both having cytopathogenic and noncytopathogenic strains, both can create the same manifestations of disease symptoms (Brodersen, 2014). In addition to being immunosuppressive, noncytopathic BVDVs have the ability to cross the placental barrier and create persistently infected (PI) animals, who will shed the virus their entire life.

While the mechanism that creates persistently infected animals is not clearly defined at this time, it has been observed that the window for persistent infection occurs from d 40 to 120 *in utero* (Bolin, 1995). It has been hypothesized by Peterhans et al. (2003), that interferon-τ may be driving the inability of BVDV to establish PI in fetuses before d 40 of gestation, as Alexenko et al. (1999) showed that interferon-τ can have antiviral activity similar to other type 1 interferons. Similarly, Peterhans et al. (2003) has hypothesized that fetuses greater than 120 d of gestation produce their own interferons, protecting them from persistent infection.

Even though the efficacy of BRD vaccines is the subject of much research and debate, particularly between the findings of studies that utilize a natural exposure model and those that utilize a challenge model (Theurer et al., 2015), they are used in 96.6% of feedlot operations (USDA, 2011). Runyan et al. (2014) showed with previous research in the same cattle as this project, that vaccination protocols, regardless of type (killed virus or modified-live virus), improved animal performance following BVDV challenge even when clinical symptoms were not observed. Moreover, it was suggested by Smith et al. (2017) that a modified live BVD vaccine may mitigate the negative feeding performance effects of a directly administered BVDV challenge more effectively than killed virus or non-vaccination. Ridpath et al. (2007) hypothesized that poor vaccine efficacy may be due to variation among BVDV strains. It was also suggested by Ridpath et al. (2007) that individual vaccines may be more effective than others, even when comparing modified-live virus (MLV) vaccines to one another, likely due to strain differences. Fulton et al. (2002) noted that most BRD vaccines contained BVDV type 1a strains, which may not confer protection against type 1b challenge.

Effects of BRD vaccines on carcass traits are not widely reported, except through corresponding animal health differences. Schunicht et al. (2003) observed that crossbred bull and steer calves of approximately 8 to 10 months of age in a typical commercial feedlot setting, had carcass weight differences due to vaccine treatment. Animals receiving a univalent MLV vaccine only containing only infectious bovine rhinotracheitis (IBR) antigen had 2.8 kg lower carcass weights than animals receiving multivalent MLV vaccines containing IBR, parainfluenza-3 (PI-3), BVDV, and bovine respiratory syncytial virus (BRSV). Additionally, lower rates of fever were seen in animals receiving a multivalent vaccine when compared to animals receiving a univalent vaccine, leading to lower rates of treatment for BRD symptoms. These led to a $0.74 per animal advantage for animals receiving a multivalent vaccine, suggesting that it is more cost-effective to utilize multivalent vaccines

Often, animals with BRD are clinically asymptomatic, as evidenced by lung lesions present in nearly equal frequencies between animals that were treated for signs of respiratory infection, vs. those that were not (Gardner et al., 1999; Wittum et al., 1996). Downey-Slinker et al. (2016) described that 41% of the Angus-Nellore steers used in the present study showed thrombocytopenia, 55% showed lymphopenia following BVDV challenge. Even though both of these traits are symptoms of BVDV infection, only 14% of animals exhibited clinical symptoms, with all cases being mild. This gives credit to statements by multiple authors that phenotypic complexity and unobservable subclinical symptoms are likely key contributors to low heritability estimates for BRD susceptibility based on “healthy vs. morbid” classification, as well as being a root cause for un-improving morbidity rates in the field (Snowder et al., 2006; Neibergs et al., 2014;

Runyan et al. 2014).

Feeding Behavior and Economic Impacts of BRD

Sowell et al. (1999) reported through two trials that feeding behaviors between healthy and morbid feedlot steers were different. Healthy steers spent an average of 60 minutes per day at the feed bunk, compared to 46 minutes in morbid steers (trial 1). However, watering behavior did not differ during the first four days of the feeding period, but healthy calves had 1.4 more drinking bouts per day than morbid calves for the entire feeding period. Smith et al. (2017) found in steers of this study that dry matter intake (DMI) decreased following BVDV type 1b challenge. When this is combined with the results of Kayser and Hill (2013) that animals who consumed less had lower average daily gain, it can be assumed that at an equal number of days on feed, animals who are morbid will have lower live weights, and thus, lower carcass weights, as seen in the results of the Texas Ranch to Rail program (McNeill, 1999). These data showed that morbid cattle had medicine costs that were approximately $26 per head higher than healthy calves, while gaining an average of 0.19 kg/d less than healthy calves, and having lower-grading carcasses than their non-morbid counterparts, leading to a 5-year average loss of $93.20 per morbid animal (McNeill, 1999). Griffin (1997) estimated that animal deaths associated with bovine respiratory disease approach $1 billion of loss to producers. Adjusted for inflation using data from the Bureau of Labor Statistics (BLS, 2018) from 1997 to July 2018, it can be extrapolated that these losses would be valued at $1.57 billion in 2018-2019.

Relationships of Health Influences on Animal Performance and Carcass Outcomes

Reinhardt et al. (2012) found that a higher number of health treatments in morbid Angus feedlot steers was negatively correlated with carcass traits such as hot carcass weight, with steers not identified as needing BRD therapeutic treatment having an average of 373.2 kg carcasses, compared to 360.9 kg for steers requiring treatment three or more times. Additionally, carcass quality was impacted, with no roll cattle requiring twice as many BRD therapeutic treatments on average compared to cattle that graded prime or choice. This coincides with the findings by Gardner et al. (1999) and Waggoner et al. (2007), that steers treated for respiratory infection more than once had an average daily gain of 0.61 kg, compared to 0.695 kg in animals who were not identified for treatment. In addition, steers treated once or less than once had 82.4% of carcasses grade choice, compared to 76.9% of carcasses in steers treated more than once. This is further substantiated by Runyan et al. (2014), who observed reduced average daily gain in the first 14 d following a prescribed BVDV challenge in the Angus-Nellore steers used in the present study. Additionally, Gardner et al. (1999) found that steers without lung lesions present at slaughter had Warner-Bratzler shear force values of 2.8 kg, compared to 3.0 kg in steers than those that had active lung lesions.

While Waggoner et al. (2007) did not find a difference in hot carcass weight, fat thickness, longissimus muscle area, marbling score, or yield grade between steers not identified as needing treatment and steers presenting with, and subsequently treated for, clinical symptoms decreased profitability (attributed to a greater number in days on feed). It was found that steers not presenting with, and subsequently not treated for clinical signs of BRD returned $92.26 more profit on average than steers treated one or more times, and also found a relationship among profitability between steers with those who were treated once bringing a higher price on average than steers who were treated two or more times (Waggoner et al., 2007). This number may in reality be higher, as it did not include any differences in feed cost for healthy versus morbid animals.

It was suggested by Waggoner et al. (2007), that delaying harvest of steers that were treated would possibly allow for overall carcass composition to recover to a level similar to cohort animals that were not treated. However, this would require a cost-benefit analysis by the producer at the time of decision in order to determine if the increased carcass value would be greater or less than the cost required to feed and house the animal for the extended time, and would also require a risk analysis in order to determine the probability of repeated morbidity during the extended feeding period. Moreover, this idea was contradicted by Wilson et al. (2017), with findings that despite a greater number of days on feed in order to reach a similar endpoint to nonmorbid animals, morbid animals had lower hot carcass weights, marbling scores, and loin muscle area, with all values decreasing linearly, corresponding with 0 to 4 treatments administered, and slaughtered at a common backfat thickness.

Vaccine treatment has also been found to be important to feeding behavior post-challenge. According to Smith et al. (2017), the challenged Angus-Nellore steers in the present study that received a modified live virus experienced a lower reduction in feed intake when compared to steers who received a killed virus or were not treated with a vaccine. This was coupled with, and likely driven by steers who received a modified live virus vaccine having a greater duration of bunk visit events, greater meal frequencies, and slower eating rates when compared to steers who received a killed virus or no vaccine treatment. Whether these differences could carry over to impacts on carcass traits is unknown, however. Ridpath et al. (2010) and Ridpath (2013) found that modified live vaccines also caused lower levels of lymphocyte decline, with lower levels of antibodies, showing lowest levels of pyrexia (presenting >40° C rectal temperature at any time). However, it was noted that modified live vaccines were no more effective than killed vaccines when it comes to preventing viremia (Ridpath et al. 2010).

In a companion analysis to the present study, animals who received a modified live virus vaccine treatment for BVD showed lower antibody titers for BVD and IBR and less pronounced lymphocytopenia and thrombocytopenia at 14 d after BVDV challenge, when compared to animals who received a killed virus vaccine (Downey-Slinker et al., 2016). However, there has been variation shown among groups of cattle receiving different types of modified-live vaccines. Bryant et al. (2008), among steers receiving modified-live vaccines, found that steers receiving Pyramid® 5 (Bohringer Ingelheim, Ridgefield, CT, U.S.) vaccines had different relapse rates of BRD symptoms than steers receiving Bovi-shield Gold® 5 (Zoetis, Parsnippany Hills, NY, U.S.) and Bovi-shield IBR-BVD (Zoetis, Parsnippany Hills, NY, U.S.), with 4.2% and 3.6% lower relapse rates, respectively.

Genetic Components of BRD Incidence

While the effects of hybrid vigor are well documented for overall animal health (Bunning et al., 2018), it is notable that in a study by Snowder et al. (2005), incidence of BRD was less in *Bos taurus* crossbred compared to purebred steers. Additionally, Reinhardt et al. (2009) found that Continental steers required an average of 0.15

therapeutic treatments for BRD per animal, compared to 0.08 average therapeutic treatments for English or English and Continental cross steers in a typical feedlot environment, with all groups having various ages of steers. Furthermore, crosses containing British by Continental or the tropically adapted breeds of Brahman, Boran, and Nellore, which exhibited lower incidence of BRD when compared to calves created through crossing two British breeds (Snowder et al., 2005). In another study, Snowder et al. (2006) found that some breeds were generally more susceptible to BRD than others with clinically observed incidence rates ranging from 8.34% in Hereford, to 18.85% in Braunvieh. These breed differences imply there are genetic components for BRD resistance or susceptibility, and from there, selection could be used to reduce incidence throughout the population. However, it may be possible that breeds with lower observed incidence of BRD may simply be better at masking symptoms, as subclinical illness was not quantified in Snowder's study. Hilton (2014) identified selection as a potentially effective way to decrease BRD susceptibility without additional intervention.

Even though a clinical phenotype may not be a reliable indicator of true level illness when compared to subclinical phenotypes, phenotypic selection for increased population resistance to BRD may be a successful practice over time. As previously discussed, even though subclinical animals are not reliably detected in many studies until slaughter, animals that present clinical symptoms do have reduced performance from those that are subclinical or healthy (Waggoner et al., 2007; Reinhardt et al., 2012), with subclinically ill animals having lower performance than animals that remain healthy (Gardner et al., 1999), suggesting that selection against clinical phenotypes may be successful in selecting for animals with greater resistance to BRD pathogens. However, some producers may be inadvertently selecting against it already. In broiler lines selected for a higher rate of growth, lower antibody responses were seen to sheep erythrocytes when compared to a line selected for lower body weight (Miller et al., 1992). In a meta-analysis of similar projects by van der Most et al. (2010), lines of poultry that had been selected for increased growth showed decreases in immune function, but among lines of poultry selected for immune function, the effect on growth was near zero. If a similar relationship were found in beef cattle, it would mean that as producers place emphasis on growth traits they could be inadvertently, but simultaneously, suppressing immune function.

This idea may explain some of the increase observed in an analysis by Loneragan et al. (2001), where it was found that cattle had relative risks of 1.16, 1.35, and 1.46 for mortality due to respiratory tract disorders compared to cattle in the reference year, in 3 out of 5 years, along with overall mortality increasing from 10.3 deaths to 14.2 deaths per 1000 cattle. This finding occurred during a time in which post weaning gain has increased (Angus Association, 2019). In a study by Miles (2009), it was found that comparing medicine cost per head and % death loss from 1989 to 2008, it was found that in cattle weighing between 295and 408 kg, medicine costs have increased from approximately $1.25/animal in 1989 to $3.00/animal in 2008. In the same study, it was found that average death loss in 295 to 408 kg animals increased from 0.75% in 1989 to just over 1.00% in 2008 (Miles, 2009). While some of this is due to an increase in drug costs, it is believed that cattle are heavier per day of age, requiring a greater amount of these drugs to be used per treatment event (Miles, 2009).

Neibergs et al. (2014) found that with an average BRD complex (BRDC) prevalence of 16.2% in U.S. feedlots with a capacity greater than 1,000 head, the average rates of genetic change for susceptibility to BRDC when selecting the top 30% of individuals were 2.08%, as defined by clinical scores in a quantitative scoring system. This study also estimated heritability at 0.292, which corresponds to the highest value of 0.26, found by Snowder et al. (2005). However, Snowder et al. also reported that the low estimates of heritability may be related to the large variation in clinical symptoms, or measurement error of disease detection. This is concept supported by Wittum et al. (1996), who reported that only 50% of all steers with pulmonary lesions at slaughter had been detected as having BRD symptoms during the feeding period. Similar results have been reported in studies by Gardner et al. (1999) as well as Thompson et al. (2006), with 29% and 29.7% of cattle not treated for BRD clinical symptoms presenting with lung lesions, respectively. Overall, a highly successful method of managing BRD and BVDV outbreaks is preventing them in the first place. While the use of vaccinations for prophylaxis and individual animal treatment plans are in place in many operations, identifying and utilizing a sufficient number of animals that are resistant or tolerant to both the viral and bacterial components of BRD, in order to decrease the spread to susceptible animals will be a critical tool in shifting the paradigm from one of reactivity to one of proactivity.

As stated previously, the type of vaccine also seems to be highly influential in immune response and overall ability of the animal to ward off the virus. These vaccines also seem to play a role in subsequent immune challenges, and gene regulation in treated animals. The results of Downey-Slinker et al. (2016) point toward modified live virus vaccines as a better option when considering future challenges. However, as demonstrated in Bryant et al. (2008), even variation within vaccines of the same type can exist. Among three different types of modified-live virus vaccines, trends were seen for steers receiving Pyramid 5® (Bohringer Ingelheim, Ridgefield, CT, U.S.) had 3.8% better feed conversion than animals receiving Bovi-Shield Gold IBR-BVD (Zoetis, Parsnippany Hills, NY, U.S.) vaccine. A similar trend was also identified for morbidity rates, with animals receiving Pyramid 5® (Bohringer Ingelheim, Ridgefield, CT, U.S.) having 11% fewer cases of morbidity when compared to animals receiving Bovi-Shield Gold® 5 (Zoetis, Parsnippany Hills, NY, U.S.), as well as a 22% lower relapse rate.

Temperament and Handling on Animal Responses

Individual temperament and animal handling may also contribute to susceptibility to illness, altered feeding behavior, and carcass outcomes (Fell et al., 1999; Smith et al., 2017; Olson et al., 2019). Fell et al. (1999) found that calm cattle performed better in the feedlot than nervous cattle, gaining 1.46 kg/day and 0.95 kg/day, respectively. Moreover, no calm animals were identified for health problems, whereas 5 of 12 nervous animals were taken to the hospital pen at some point during the feeding period (Fell et al. 1999). While temperament may be highly variable from one animal to the next, it has been shown to be moderately heritable (Le Niendre et al., 2002), indicating that selection for docile animals could improve their susceptibility to morbidity, and improve carcass outcomes. Riley et al. (2014) found overall heritability for temperament traits to be 0.47 to 0.55 in Nellore-Angus crosses, based on model used. Defining a ‘favorable’ phenotype for animal temperament may depend upon the production phase of that animal. For cow-calf operators in more extensive situations, it is advantageous to select for cows with protective maternal temperament, which leads to greater rates of calf survival (Grandinson, 2005), even though cows with a temperament that is too excitable at breeding may experience reduced pregnancy rates, and be difficult to handle (Cooke, 2014). However, once the offspring of these cows reach the feedlot, an excitable temperament is less advantageous (Bates et al., 2014).

It was suggested by Curley et al. (2007), that higher concentrations of base-level serum cortisol seen in excitable cattle, as well as elevated cortisol levels that last longer, could mean that easily excitable cattle experience chronic stress, leading to suppressed immune systems, as well as decreased deposition of protein and fat when compared to their non-excitable counterparts. Bates et al. (2014) studied the interactions between temperament and growth traits, and found that excitable cattle gain less in a feedlot setting, based on the observed correlation of -0.117 between total gain and chute exit velocity. Fang et al. (2012) identified small to moderate correlations involving temperament with antibody titers and hematological responses post BVDV challenge in these steers. Bates et al. (2014) also found that cattle can be identified upon entry into the feedlot through chute score, which was also found to have a negative correlation with marbling score. This information could potentially be utilized to group excitable cattle together, who may have a higher risk of being immunocompromised, such as acclimating excitable animals to human handling.

It was found by Cooke (2014) that animals were able to acclimate to human handling in order to reduce circulating blood plasma cortisol in animals in feedlot environments. This finding could be effective at reducing the incidence of the BRD complex. Due to their nature, excitable animals may experience increased and prolonged stress responses when compared to their non-excitable contemporaries, particularly during handling events in novel environments such as a feedlot.

Regardless of excitability, handling can cause stress to cattle, and even appropriate handling events can cause variable stress levels among animals, depending on the animal's perception of the handling experience (Grandin and Shivley, 2015). Stress can cause cattle to deplete glycogen stores before slaughter, leading to dark cutting carcasses (McVeigh et al., 1982), which are largely discounted by packers. Moreover, it was found by Fordyce et al. (1985) that there was a tendency for bruising and temperament score to be related, indicating that docile cattle experienced less carcass bruising than their excitable contemporaries, and was speculated that this was a function of an animals' own temperament, rather than their herd mates.

Dam Effects on Health and Carcass Traits

While age of dam effects and adjustments for birth and weaning weights have been widely accepted, these potential effects on calf immunity and feeding performance have not been as broadly discussed. Wittum and Perino (1995) quantified the effects of passive immunity on calves before and after weaning, as well as growth performance of calves finished in a typical feedlot environment. IgG concentrations in calves have been shown to be influenced by age of dam, with IgG levels increasing as age of dam increased (Muggli et al., 1984). Wittum and Perino (1995) found that calves experiencing morbidity and mortality due to BRD prior to weaning also fell into groups with the lowest concentrations of serum IgG and plasma proteins taken from samples taken 24 hours postpartum. Furthermore, calves with inadequate plasma protein concentrations at 24 hours of age were associated with approximately 3 times greater risk of respiratory tract morbidity in the feedlot (Wittum and Perino, 1995). These results indicate that as a dam ages, her offspring should have a lowered risk of respiratory tract morbidity when compared to calves with younger dams.

Beef Improvement Federation (BIF) guidelines (BIF, 2018) describe a relationship of age of dam to birth weight, weaning weights, but do not describe any relationship beyond weaning, as these influences are usually thought to be not significant. However, Da Silva et al. (2016) found that the effect of dam's age is present among carcass traits, as well, indicating that carryover effects of age of dam should be considered. Da Silva et al. (2016) found that steers born to 2 or 3-year-old dams had lighter carcasses, with more carcasses grading Choice and upper 2/3 Choice. Additionally, final body weights and hot carcass weights were higher for steers born to dams 4 to 9 years of age, with overall body weights, ribeye area, and hot carcass weights increasing until dams reached 7 to 8 years of age, at which point offspring performance began to decline. This relationship may be partially explained by overall maturity of the dam and her corresponding body size. Younger females who are still developing will not be at their mature weight, which is likely influencing the weight of calves at birth. Similarly, body weight of females beyond 8 years of age may begin to decline when compared to females within the 5-8 years of age group.

Summary

Feedlot cattle experience a host of stressors, including immune challenges and many novel experiences, such as feedstuffs and feeding situations, various animal handling styles and physical environments that can affect performance traits. Additionally, some animals have poor genetic predisposition to lowered feedlot performance when compared to contemporaries, leading to potential interactions between genetic and environmental components, which add variability to various phenotypes for performance traits. Regardless, effects of bovine respiratory disease complex continue to be a large economic burden on the cattle industry. Cow-calf producers could benefit from lowered BRD incidence through selection for appropriate temperament and resilience to BRD pathogens; at least part of this resilience may be recognized through evaluation of traditional performance traits such as ADG and feed intake, which could be utilized to identify morbid animals, which in turn influence carcass merit.

The hypothesis for the present study, then, is that morbidity indicators early in the feeding period in response to BVDV exposure, will influence traditional carcass measurements in a fashion similar to what has been reported in other studies for generalized BRDC (Gardner et al., 1999; Waggoner et al., 2007; Reinhardt et al., 2012; Runyan et al., 2014). Therefore, the objectives for this study were to utilize a defined BVDV challenge model to: (1) evaluate the effect of average daily gain and dry matter intake immediately after BVDV exposure on traditional carcass measurements, (2) utilize individual animal background information such as breed composition and age of dam to explain variation among carcass measurements, (3) investigate the effect of vaccine protocol and traditional respiratory disease response measurements such as presence of clinical symptoms and pyrexia on carcass outcomes, and (4) evaluate possible relationships among the independent variables of lung scores, clinical symptoms, average daily gain classification, intake classification, and temperament classification.

MATERIALS AND METHODS

All animal methods and protocols were approved by the Texas A&M University Institutional Animal Care and Use Committee and the Texas A&M University Institutional Biosafety Committee.

Animals

Half-blood Angus-Nelore (F_2 and F_3) yearling steers sourced from the Texas A&M University McGregor Genomics herd were utilized. This population is a *Bos taurus- Bos indicus* crossbred population developed for genomic studies. F_2 steers were made in 4 possible combinations of F_1 matings, where Angus-sired (AN) and Nellore-sired (NA) F_1 sires were mated to AN and NA F_1 females to produce F_2 progeny, noted as ANAN, ANNA, NAAN, and NANA throughout this study. F_3 steers were produced through mating F_2 NANA sires to F_2 NANA dams. Both F_2 and F_3 steers were born and evaluated in all four years of the study. Frequency distribution of animals through all four years of the study are presented below in Table 1.

Table 1. Frequency distribution of calf types across years of the present study.

Year	NANA	ANAN	NAAN	ANNA	F_3	Total
2010	10	.	.	14	51	75
2011	20	4	12	16	51	103
2012	11	9	9	16	51	96
2013	18	9	10	14	33	84
Total	59	22	31	60	186	358

Labels across columns denote breed makeup of calves, with the first two letters denoting the sire's breeding, and the second two denoting the dam's. F_3 calves were made by crossing F_2 NANA animals. Labels across rows denote age of dam of the steers evaluated.

Steers utilized in this study were spring-born in 2009, 2010, 2011, and 2012. Steers were castrated and vaccinated for clostridial diseases, but were not vaccinated against bovine respiratory disease (BRD) pathogens prior to weaning. Steers were vaccinated for clostridial diseases, and were weaned at approximately 7 months of age.

Each year, steers were subjectively evaluated for temperament approximately 6 weeks post-weaning by a panel of four evaluators on a 1-to-9 scale where 1 = animal was totally calm, quiet, and non-reactive when isolated, and 9 = animals that were highly aggressive, reactive, and a potential health threat to themselves and evaluators. These procedures and analyses were reported by Riley et al. (2014). While temperament was investigated as a potential source of variation among carcass traits in preliminary models, it was not included in final models because it was not found to be a significant contributor to variance in carcass traits.

Post-weaning, calves were managed as one group where they were either fed a growing ration or placed on pasture, depending on the year, until they were transported approximately 165 km to the Beef Cattle Systems Research Unit near College Station, TX in either January or February. Throughout this study, low-stress cattle handling methods were emphasized during movement, processing, and data collection.

All steers were tested and confirmed to be free of BVDV persistent infection via ear notch sampling. Ear notch samples were tested through immunohistochemistry or antigen-capture ELISA, and steers were confirmed to be seronegative for BVDV antibodies through serum virus neutralization assay. Immunological testing was performed by the Texas Veterinary Medical Diagnostic Laboratory (TVMDL, Amarillo, TX). These assays and their corresponding results were described in detail by Downey-Slinker et al. (2016).

Vaccine treatments

Steers were stratified by sire and genomics cow family of the McGregor Genomics population, which created the designation of "calf type" in the present study. Steers were assigned to one of three BRD vaccine strategies, which utilized modified-live (MLV), killed (KV), or no (NON) vaccine treatment, administered at approximately 12 months of age. Steers receiving KV had an initial dose of Vira Shield® (Novartis Animal Health US, Inc., Greensboro, NC) injection on d -56 or -49 pre-challenge, and a booster on d -35, -28, or -25, relative to viral challenge, targeting 21 d between primer and booster vaccinations. Steers receiving MLV were vaccinated with one dose of Arsenal® 4.1 (Novartis Animal Health US, Inc., Greensboro, NC) on d -35, -28, or -25 relative to challenge, in concurrence with the administration of the KV booster. Both KV and MLV of vaccines are licensed to aid in control of infectious bovine rhinotracheitis (IBR), parainfluenza-3 (PI-3), bovine respiratory syncytial virus (BRSV), and BVDV. The same vaccines were used in all years. Steers assigned to the non-vaccinate treatment (NON) did not receive viral vaccination nor a sham injection prior to BVDV challenge. Steers receiving MLV were kept separated, with no nose-to-nose contact possible, from KV and NON-treated steers for 7 to 10 following MLV injection. Treatment groups were commingled within pens following this initial separation.

Viral challenge

Steers were challenged on d 0 with a non-cytopathic type 1b BVDV strain (CA0401186a) obtained from the USDA-ARS National Animal Disease Center (NADC)

(Ridpath et al., 2007). This strain was isolated from a persistently infected (PI) calf and submitted to the NADC from the Tulare laboratory of California Animal Health and Food Safety Laboratory. Each steer was administered 5 mL of inoculum (1 x 10^5 TCID/mL) by placing 2.5 mL in each nasal passage; each animal's nose was raised until it was visually observed that the steer had swallowed, confirming the challenge virus had passed through the nasal sinuses. The particular strain of BVDV was chosen because it had been reported to cause observable but mild clinical signs of morbidity monitored in the present study without risk of extreme morbidity or mortality. (Ridpath et al., 2007). Additionally, BVDV type 1b has been reported as the most prevalent strain in morbid North American feedlot cattle (Hilton, 2014).

Sample and data collection

Body weights and rectal temperatures were recorded on d 0 (day of challenge), 3, 7, 10, 14, 28, and 42. Pyrexia classification in the present study (rectal temperatures ≥ 40ºC = pyrexia) was determined from observed rectal temperatures on d 3, 7, 10, and 14. Order of processing (pen sequence) was rotated during processing across sample collection days to prevent potential confounding sequence with responses.

Daily feed intake and feeding performance were recorded through the GrowSafe® (Growsafe, Ltd., Calgary, AB, Canada) automated collection system, which records data from midnight to midnight daily. Diet composition and results regarding daily feed intake and behavior were described in detail by Smith et al. (2017). These data were utilized to determine cumulative feed intake, which in turn was investigated for influence on carcass merit.

Clinical observations were conducted twice daily for the first 14-day period, and then once daily for d 14 to 42, with a scoring system from 0 (no clinical symptoms), or 1 to 5 (least to most severe) for commonly associated symptoms of BRD/BVD, including cough, ocular and nasal secretion, depression, diarrhea, and gauntness/shrink. The threshold for potential therapeutic treatment in which an animal would be removed from its pen was any observed clinical symptoms scoring 3 or above. No steers in the present study were identified as having clinical symptoms severe enough to warrant potential therapeutic treatment. Animals exhibiting rectal temperatures greater than 40.0ºC were administered tulathromycin (Draxxin, Zoetis, Parsnippany Hills, NY, U.S.) according to label directions, regardless of the presence of clinical symptoms. This practice was done in accordance with the animal use protocol (AUP) of the project. The same personnel evaluated cattle in all 4 years of the project. Following challenge and the subsequent 42d feeding period, steers were transported 210km from Texas A&M's experimental feedlot to a commercial feedlot in South Texas for finishing.

Upon arrival at the feedlot, cattle received booster vaccinations for BRD and clostridial diseases, injectable parasiticide, and a long-acting growth implant. Cattle also had tail switches bobbed and horns tipped if needed. Each year steers were housed in a single pen and transitioned from a receiving diet to a finishing diet over a 21-d period; cattle were placed on feed for approximately 150 to 180 d prior to harvest depending on the year. Steers were scheduled for harvest when the feedlot management observed adequate external fat cover and decreasing feed intake. All steers were presented for slaughter on the same day within a year.

Steers were transported from the feedlot at approximately 0700 on day of harvest, 225 km to a commercial beef packing plant. At harvest, lungs were visually evaluated with a subjective 1-to-5 scale where: 1= pink, healthy lung with no discoloration, 2 = < 25% discoloration, 3 = 25% to 50% discoloration, 4 = 50% to 75% discoloration, and 5 = >75% discoloration. Carcasses were graded after approximately 48-h of chilling by Texas A&M University meat science personnel, collecting carcass weight, longissimus muscle area, 12th rib fat thickness, KPH fat percentage, marbling score, lean maturity, skeletal maturity, lean color, and hump height.

Statistical analyses

All statistical analyses were carried out using mixed model procedures in SAS 9.4 (SAS Inst. Inc., Cary, NC). Preliminary models were evaluated to investigate fixed effects of year, calf type, vaccine treatment, lymphocyte decline, pyrexia status, clinical signs, feeding performance, age of dam, and d 0 weight (as a covariate). These preliminary models were created by including all effects of interest within a category (health traits, and individual animal traits) in conjunction with weight gain ranking, and then cumulative feed intake ranking, For each carcass trait, full models were evaluated and subsequently altered where the effects with largest, non-significant *P*-values were removed one at a time until only variables that approached significance ($P \leq 0.15$) remained for final models. Sire and pen nested within year were included as random effects in all final models. The animal traits associated with BRD morbidity that have been documented in other studies were of interest as potential independent variables to evaluate differences in the response variables of hot carcass weight, longissimus muscle area, marbling score, and adjusted fat thickness. These response variables will be referred to as “carcass merit” through the remainder of the present study.

Relationships between independent variables were also evaluated and presented through frequency distributions, which were tested through Chi-square tests. No two-way distributions among these variables were different ($P < 0.05$) from the overall, single factor distributions and, thus, further evaluations were not conducted on these relationships.

Preliminary Models Incorporating Health Traits

Lymphocyte decline, pyrexia status, vaccine type, and clinical signs were utilized in the present study to evaluate individual animal health outcomes. Lymphocyte decline was gathered as a continuous variable, but evaluated in accordance with Downey-Slinker et al. (2016), with steers having a lymphocyte decline greater than 40% being classified as “yes” and steers having a lymphocyte decline less than 40% being classified as “no” for the variable “lymdecline”. Pyrexia status classified in a similar fashion, with steers having an observed rectal temperature ≥ 40°C in the first 14 days being classified as “yes” and steers not presenting rectal temperature ≥ 40°C in the first 14 days being classified as “no” for pyrexia.

Clinical symptoms were evaluated on a scale from 0-to-5 scale, with 1 being the least severe symptoms, and 5 being the most severe. Steers having a score ≥ 1 for any observed clinical symptoms being classified as “yes” for clinical signs, and steers having a 0 for all clinical symptoms being classified as “no” for clinical signs. These clinical symptoms include cough, nasal and ocular discharge, depression, diarrhea, and gauntness/shrink. No steers in this study presented clinical symptoms that scored higher than 2 on this scale, likely due to the chosen strain of BVDV. Frequency distribution of steers among these classifications are described in Table 2 below.

Table 2. Frequency distribution of steers across health measures

	Pyrexia[1]	Clinical Symptoms[2]	Lymdecline[3]
Yes	219	50	156
No	143	312	200
Total	362	362	356

[1]No = no rectal temperature ≥ 40° C observed in the first 14 days, Yes = rectal temperature ≥ 40° C observed in the first 14 days. [2]No = no sign of morbidity in the first 14 days, Yes = any sign of morbidity in the first 14 days.[3]No = lymphocyte decline did not exceed ≥ 40% in the first 14 days, Yes = lymphocyte decline of ≥ 40% in the first 14 days.

Vaccine type was placed into preliminary models as well, as it was of interest to evaluate possible variation in carcass merit based on the type of vaccine administered. Frequency distribution of steers among these classifications are described in Table 2 below. Frequency distribution of steers between vaccine types is described in Table 3 below.

Table 3. Frequency distribution of steers across vaccine treatments

Vaccine Type	KV	MLV	NON	Total
n	120	124	118	362

KV = Killed Virus vaccine, MLV = Modified-Live Virus vaccine, NON = Control animals, not receiving vaccine treatment.

Preliminary Models Incorporating Feeding Performance

Steers had feeding performance evaluated utilizing a GrowSafe® (Growsafe, Ltd., Calgary, AB, Canada) system, where DMI was continuously monitored. With this data, average daily gain (ADG) was calculated as total gain within the first 14 days divided by 14. Gain to feed ratio (G:F) was calculated as total gain within the first 14 days divided by total intake within the first 14 days. Summary statistics for ADG and Intake for the first 14 days are presented in Table 4 below.

Table 4. Summary statistics for average daily gain and cumulative feed intake measured per animal d 0 to 14 post BVDV challenge.

Variable[1]	Mean	SD	CV	Minimum	Maximum
ADG kg/d	0.67	0.69	102.864	-1.88	3.05
Intake, kg	57.92	12.66	21.867	13.74	97.49

Each of these variables was subsequently split into five groups, targeting an equal number of animals in each, roughly 20% per level, providing the discrete category levels of "lowest", "low", "average", "high", "highest", corresponding to the respective levels of production traits. Previous research on these data (Runyan et al., 2017) documented highly variable levels in these performance traits during the 14 d post-challenge, therefore it was of interest to investigate whether these performance differences might influence carcass traits 150 to 180 d later. Summary statistics for ADG and Intake for the first 14 days are presented in Table 4 below. Frequency distributions of ADG and intake in the first 14 days are described in Table 5 below.

Table 5. Frequency distribution and range of feeding performance categories

	Lowest	Low	Average	High	Highest
ADG	78	63	80	61	77
Range, lb/d	-1.879 to 0.130	0.195 to 0.454	0.518 to 0.842	0.907 to 1.231	1.296 to 3.044
Intake	72	72	74	73	71
Range, kg	13.737 to 47.043	47.134 to 55.007	55.043 to 61.016	61.211 to 67.941	68.227 to 97.492

Labels across columns denote ranking, with rankings assigned to create nearly equal distribution of animals.

Preliminary Models Investigating Individual Animal Background Traits

Steers were stratified between treatments based on sire and genomics cow family, yielding the variable of “calf type” balanced across treatments. This variable was utilized to investigate potential differences between the different cross types of NANA, NAAN, ANAN, ANNA, and F_3 steers.

Temperament scores were assigned approximately 6wk after weaning on a 1-to-9 scale (best to worst), and temperament categories were assigned as Calm (scores ≤ 3.80), Moderate(scores of 3.81 – 6.0), and Wild (scores ≥ 6.01). Frequency distributions of temperament categories are presented below in Table 6.

Table 6. Frequency distribution of animal temperament classifications

Temperament	N	Average score
Calm	118	2.345
Moderate	117	5.220
Wild	122	7.014

Temperament scores were assigned approximately 6wk after weaning on a 1-to-9 scale (best to worst), and temperament categories were assigned from mean value ± 0.5 SD as Calm (scores ≤ 3.80), Moderate(scores of 3.81 – 6.0), and Wild (scores ≥ 6.01).

Age of dam was also utilized to investigate potential effects on carcass merit. Age of dam categories were based on BIF (2018) guidelines. This classification placed steers into four separate groups, with ages of dams falling into the categories of “three”, “four”, “five-ten”, “eleven-seventeen” for the variable “AOD”. Frequency distribution of calf type by age of dam is shown below in Table 7.

Table 7. Frequency distribution of calf type across age of dam classification

	Calf Type					
Dam age, yr	ANAN	ANNA	NAAN	NANA	F3	Total
Three	6	4	14	3	15	42
Four	9	11	8	5	29	62
Five - Ten	5	11	6	6	142	170
Eleven- Seventeen	2	34	3	43	0	82
Total	22	60	31	57	186	356

Labels across columns denote breed makeup of calves, with the first two letters denoting the sire's breeding, and the second two denoting the dam's. F_3 calves were made by crossing F_2 NANA animals.

RESULTS AND DISCUSSION

A general summary of the carcass and performance traits that were evaluated is presented in Table 8. Several traits of these steers were of interest to investigate for potential influences on carcass traits, and several of the frequency distributions across other experimental effects are discussed.

Table 8. Summary statistics of carcass traits analyzed in the present study.

Variable[1]	Mean	SD	CV	Minimum	Maximum
HCW, kg	375.14	42.50	11.330	264.85	529.48
AFT, cm	1.55	0.58	37.498	0.30	3.96
LMA, cm^2	84.66	8.99	10.623	58.71	107.74
Marbling	401.53	74.73	18.610	230	750

[1]HCW = hot carcass weight, AFT = adjusted fat thickness, LMA = longissimus muscle area, Marbling score of 400 corresponds to $Small^{00}$.

Lung Scores at Harvest

While not included in final models, lung scores were investigated as a potential source of variation in carcass outcomes in preliminary analyses. The distribution of lung scores across vaccine treatments is shown in Table 9. Distribution of lung scores did not differ across vaccines treatments.

Table 9. Frequency distribution of lung scores by vaccine treatment group.

Vaccine Treatment	Lung Score 1	2	3	4	Total	Average lung score
KV	30	62	24	3	119	2
	0.252	0.521	0.202	0.025	0.331	
MLV	34	69	19	1	123	1.894
	0.276	0.561	0.154	0.008	0.342	
NON	36	67	14	1	118	1.831
	0.305	0.568	0.119	0.008	0.328	
	100	198	57	5	360	

KV = Killed Virus vaccine, MLV = Modified-Live Virus vaccine, NON = Control animals, not receiving vaccine treatment. Whole numbers represent animal counts, decimals below represent percent.

Because differences in average lung scores were not statistically different between vaccine treatment groups, they were not included in the final model for investigation for impacts on carcass traits. Few lungs belonging to animals in this study had lung scores high enough to indicate prior illness; this corresponds to our assessment of clinical symptoms, of which none were observed to be severe enough to warrant removing an animal from its pen for potential therapeutic treatment. Frequency distributions of clinical symptoms across lung scores are displayed below in Table 10. Distribution of lung scores did not differ in the presence or absence of clinical symptoms.

Table 10. Frequency distribution of mild clinical symptoms across lung scores.

	Lung score					
Clinical Symptoms[1]	1	2	3	4	Total	Average lung score
No	83	172	51	5	311	1.929
	0.267	0.553	0.164	0.016	0.864	
Yes	17	26	6	0	49	1.776
	0.347	0.531	0.122	0.000	0.136	

[1]No = no sign of morbidity, Yes = any sign of morbidity. Animals were evaluated twice per day by the same evaluator across all years. Only minor signs (1 or 2 on a 1- to -5 scale) of depression, coughing or gauntness were observed. Whole numbers represent animal counts, while decimals below represent row frequency.

It is thought that animals having lung scores of 4 (or 5) likely indicate prior illness. Throughout many analyses (Thompson et al., 2006; Schneider et al., 2009), lung lesions without the presence of clinical symptoms have been documented and likely indicate subclinical BRD illness. As stated by Griffin (2014), subclinically ill animals suffer from condemnation of offal, lowered quality grades, and lower carcass weights, leading to an average of $19.44 per animal on feed not realized by feeders. The frequency distribution of the presence of clinical symptoms and the presence of pyrexia in steers is shown below in Table 11. Distribution of the presence or absence of clinical symptoms did not differ in the presence or absence of pyrexia.

Table 11. Frequency distribution of mild clinical symptoms with pyrexia status

	Clinical symptoms		
Pyrexia	Yes	No	Total
Yes	31	188	219
	0.620	0.603	0.605
No	19	124	143
	0.380	0.397	0.395
Total	50	312	362
	0.138	0.862	100

No = no sign of morbidity, Yes = any sign of morbidity. Animals were evaluated twice per day by the same evaluator across all years. Only minor signs (1 or 2 on a 1- to-5 scale) of depression, coughing or gauntness were documented.

A typical symptom of BVDV infection is the presence of pyrexia, and 60.5% of the steers in this study met the therapeutic treshhold of $\geq 40.0°$ C; however, a low animal count in the cell that includes both the presence of mild clinical symptoms and pyrexia is likely due to rectal temperatures being taken and recorded at predetermined regular intervals (d 3, 7, 10, and 14 post-challenge), as well as no animals presenting greater than mild clinical symptoms. This finding, and the practice of rectal temperatures taken at predetermined intervals contrasts to typical industry practices, where animals may only have rectal temperatures evaluated if other clinical symptoms are present first. Additionally, as summarized by Griffin (2014), presence of clinical symptoms does not encompass animals who are suffering from subclinical illness during the feeding period, but are later identified through lung lesions.

It was also of interest to find any associations between vaccine type and feeding performance immediately following BVDV exposure, however, these terms were also not included in the final models as they did not explain significant levels of variance for carcass merit. This finding corresponds to those by Gaspers et al. (2015) that type of vaccine caused different levels of antibody titers, but did not influence feeding behavior or average daily gain. Frequency distributions of vaccine type across intake and average daily gain rankings are illustrated below in Table 12. Distribution of ADG and Intake ranking did not differ across vaccine treatments based on Chi-square tests.

Table 12. Frequency distribution of vaccine type by average daily gain and intake rankings for the first 14d of the feeding period.

Variable	Vaccine	Lowest	Low	Ave	High	Highest	Total
	KV	21	26	29	19	25	120
		0.175	0.217	0.242	0.158	0.208	0.334
	MLV	30	20	25	21	28	124
ADG		0.242	0.161	0.202	0.169	0.226	0.345
	NON	27	17	26	21	24	115
		0.235	0.148	0.226	0.183	0.209	0.320
	Total	78	63	80	61	77	359
		0.217	0.176	0.223	0.170	0.214	1.00
	KV	25	28	22	19	26	120
		0.208	0.233	0.183	0.158	0.217	0.331
	MLV	24	18	29	26	27	124
Intake		0.194	0.145	0.234	0.210	0.218	0.343
	NON	23	26	23	28	18	118
		0.195	0.220	0.195	0.237	0.153	0.326
	Total	72	72	74	73	71	362
		0.199	0.199	0.204	0.202	0.196	1.00

Labels across columns denote ranking, with rankings assigned to create nearly equal distribution of animals. KV = Killed Virus vaccine, MLV = Modified-Live Virus vaccine, NON = Control animals, not receiving vaccine treatment.

Temperament at Weaning

Similar to lung scores, animal temperament at weaning was investigated as a potential source of variation among carcass merit traits, but was not found to be statistically significant, and was therefore not included in final models. Frequency distribution of temperament classifications across calf genetic types are described below in Table 13. Temperament distributions did not differ across calf type based on Chi-square test.

Table 13. Frequency distribution of temperament scores across calf types.

	ANAN	ANNA	F_3	NAAN	NANA
Calm	6	18	71	7	17
	0.273	0.300	0.382	0.226	0.298
Moderate	10	19	57	11	19
	0.455	0.317	0.306	0.355	0.333
Wild	6	23	58	13	21
	0.273	0.383	0.312	0.419	0.368
Total	22	60	186	31	57
	0.062	0.169	0.522	0.087	0.160

Labels across columns denote breed makeup of F_2 calves, with the first two letters denoting the sire's breeding (AN = Angus-sired F_1 sire), and the second two denoting the dam's breeding (AN = Angus-sired F_1 dam). F_3 calves were made by crossing F_2 NANA parents. Temperament classifications were assigned to average temperament scores of Calm (scores ≤ 3.80), Moderate (scores of 3.81 – 6.0), Wild (scores ≥ 6.01).

Temperament score was also investigated as a potential source of variation for animal performance and feed intake following BVDV challenge. However, temperament classification distribution was not found to be statistically different among average daily gain or intake rankings based on Chi-square tests. Temperament classifications across intake and average daily gain rankings are presented below in Table 14. Distribution of ADG and Intake classification did not differ between temperament classifications.

Table 14. Frequency distribution of temperament scores across intake and performance rankings.

Variable	Temperament	Lowest	Low	Ave	High	Highest	Total
	Calm	25	29	19	26	21	120
		0.208	0.242	0.158	0.217	0.175	0.331
	Mod	29	17	25	28	19	118
Intake		0.246	0.144	0.212	0.237	0.161	0.326
	Wild	18	26	30	9	31	124
		0.145	0.210	0.242	0.073	0.250	0.343
	Total	72	72	74	63	71	362
	Calm	27	24	23	19	26	119
		0.227	0.202	0.193	0.160	0.218	0.331
ADG	Mod	28	12	26	19	32	117
		0.239	0.103	0.222	0.162	0.274	0.326
	Wild	23	27	31	23	19	123
		0.187	0.220	0.252	0.187	0.154	0.343
	Total	78	63	80	61	77	359

Labels across columns denote average daily gain ranking and intake, with rankings assigned to create nearly equal distribution of animals. Temperament classifications were assigned to average temperament scores of Calm (scores ≤ 3.80), Moderate (scores of 3.81 – 6.0), Wild (scores ≥ 6.01).

Investigation of these potential independent variables on carcass merit and the components of the final mixed model analyses for all carcass traits are shown below in Table 15. Results are discussed sequentially for each carcass trait. For each carcass trait, effects that were included in the final models had significance levels that warranted their inclusion (P <0.10)

Table 15. Summary of significance for all main effects and interactions investigated to affect carcass traits investigated with *P*- values reported for fixed effects and variances reported for random effects.

Effect[1]	Marbling	HCW	LMA	AFT
Year	--	--	--	--
Calf type	0.023	--	--	--
Vac. type	--	--	--	0.016
Lymphopenic	--	--	--	--
Pyrexia	--	--	--	--
Clinical Symptoms	--	--	0.005	--
INTK014r	--	0.019	--	--
ADG014r	--	--	--	--
AOD	--	--	--	--
Calf type × pyrexia	0.017	--	--	--
Calf type × vaccine type	--	--	--	0.069
ADG × Clinical symptoms	--	0.054	0.035	--
Sire	0	78.965	0.028	0
Pen(year)	0	0	0	0
Residual	5424.86	8509.9	1.895	0.051

[1]Fixed effects are listed in column 1. HCW = hot carcass weight, LMA = longissimus muscle area, AFT = average fat thickness, Lymphocpenic is discrete, taking the values of yes or no, based on > 40% lymphocyte decline, and ≤ 40% lymphocyte decline, respectively. Sire and pen within year were included in all models as random effects. Significance was found at $P \leq 0.05$, but results with $P \leq 0.10$ are presented and discussed for trends. Any effect included in the final model for a particular carcass trait has an associated *P*-value.

Hot Carcass Weight

Differences in hot carcass weight were observed due to feed intake ranking 14 d post-challenge (*P* = 0.013) and presence of mild clinical signs (*P* = 0.018) Least squares means for hot carcass weight across feed intake ranking levels are shown in Figure 1.

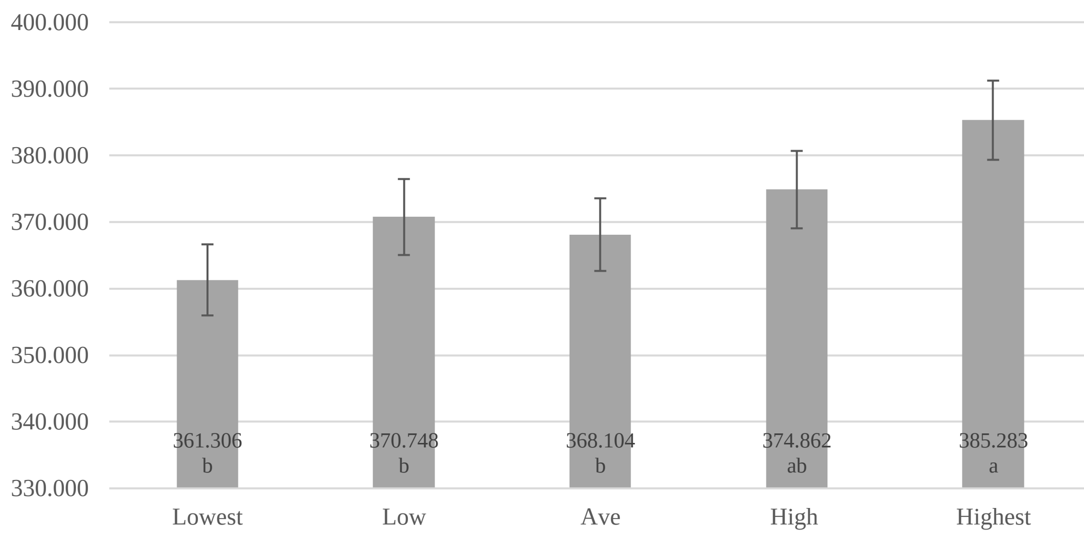


Figure 1. Hot carcass weight least squares means relative to feed intake category during first 14-d period post BVDV challenge. (Least squares means with different letters are different at *P* < 0.05.)

Steers falling into the highest feed intake level post challenge had higher carcass weights than those that fell into average (*P* = 0.017), low (*P* = 0.043), and lowest (*P* = 0.001) intake levels, with 24.0 kg difference between steers with lowest and highest feed intake ranking post challenge. Steers falling into the high intake ranking trended differently from the lowest group by 13.6 kg (*P* = 0.058), but not from the highest, average, or low intake levels.

While no animals in our study were identified as requiring potential therapeutic treatment based on severity of clinical symptoms, it should be noted that Wilson et al. (2017) identified a linear relationship between hot carcass weight and number of treatments (*P* < 0.001), with animals not identified as requiring treatment having an average hot carcass weight of 372 kg, and steers receiving three or four treatments having an average hot carcass weight of 353 kg. A potential interaction between presence of mild clinical symptoms and average daily gain ranking was identified (P = 0.054) for hot carcass weight. Interaction was likely driven by low animal numbers in some ADG levels, such as the “low” level of animals presenting clinical symptoms only having 2 animals, as well as a large standard error.

The finding of clinical BRD signs not affecting carcass weight in the present study appears to bein contrast to findings by several other studies. Schneider et al. (2009) reported that feedlot cattle of unspecified age and breed that were treated for BRD in the feedlot experienced a reduction in hot carcass weight of 8.2 kg, and is similar to findings by Roeber et al. (2001) on British and British/Continental crossbred animals. These contrasting results are likely due to the low level of virulence of our BVDV challenge strain, translating to animals only presenting mild clinical symptoms. Regardless of whether or not animals were identified as requiring therapeutic treatment at the hospital pen, Roeber et al. (2001) reported animals identified as having clinical symptoms of BRD two or more times had 9.2 kg lighter hot carcass weights than animals who were not removed to hospital pens; however, in our data, no cattle had clinical signs to the degree that animals would have been pulled from pens for potential therapeutic treatment, which is likely why we did not find a similar relationship. Holland et al. (2010) identified increasing number of BRD therapeutic treatments corresponded to decreases in hot carcass weight among British or British/Continental crossbred heifers, with animals being treated zero times, once, or twice having corresponding hot carcass weights of 343kg, 337kg, and 334kg, respectively (P = 0.03). Our findings are in contrast to Garcia et al. (2010), where no difference was observed (P = 0.12) for hot carcass weight among crossbred steers containing *Bos-indicus* influence and slaughtered at approximately 14 months of age, based on a "treated" vs. "untreated" classification for BRD illness.

The difference in findings between our study and Garcia et al. (2010) may have been due in part to differences in diagnosis or severity of clinical symptoms. A frequency table describing the relationship between intake ranking and ADG by mild clinical symptoms can be found in Table 16 below. A Chi-square test of independence was run for these variables, and distribution of clinical symptoms was not independent of feeding performance for DMI or ADG (P < .001 for both). Of the animals that presented mild clinical signs, 38% were in the lowest DMI ranking level, and 42% were in the lowest ADG ranking level; among the animals that did not present clinical signs, 17% were in the lowest DMI ranking level, and 18% were in the lowest ADG ranking level. This further substantiates findings that feeding performance can be utilized as a tool for early diagnosis of morbidity, and that morbidity will negatively impact feeding behavior (Sowell et al., 1999; Kayser and Hill, 2013; Smith et al., 2017).

Table 16. Frequency distribution of mild clinical symptoms across ADG and intake rankings.

Variable	Clinical Symptoms[1]	Lowest	Low	Ave	High	Highest	Total
	Yes	19	9	13	5	4	50
Intake		0.38	0.18	0.26	0.1	0.08	0.138
	No	53	63	61	68	67	312
		0.169	0.202	0.196	0.218	0.215	0.862
	Total	72	72	74	73	71	362
		0.199	0.199	0.204	0.202	0.196	100
	Yes	21	2	6	8	13	50
ADG		0.42	0.04	0.12	0.16	0.26	0.139
	No	57	61	74	53	64	309
		0.184	0.197	0.239	0.172	0.207	0.861
	Total	78	63	80	61	77	359
		0.217	0.176	0.223	0.170	0.214	100

[1]Evaluated on a scale of 0 = no clinical signs (No) and 1 to 5 = mild to severe presence of ocular secretion, nasal discharge, lethargy, or diarrhea; steers in this project exhibited mild clinical signs (1 and 2), with no animals exhibiting clinical signs high enough (3 or greater) to warrant pulling animals from pens for potential therapeutic treatment.

Marbling Score

Differences in marbling were observed due to differences in calf type (P = 0.023), as well as an interaction between calf type and presence of pyrexia (P = 0.017). Least squares means for marbling score units by calf type are shown in Figure 2 below.

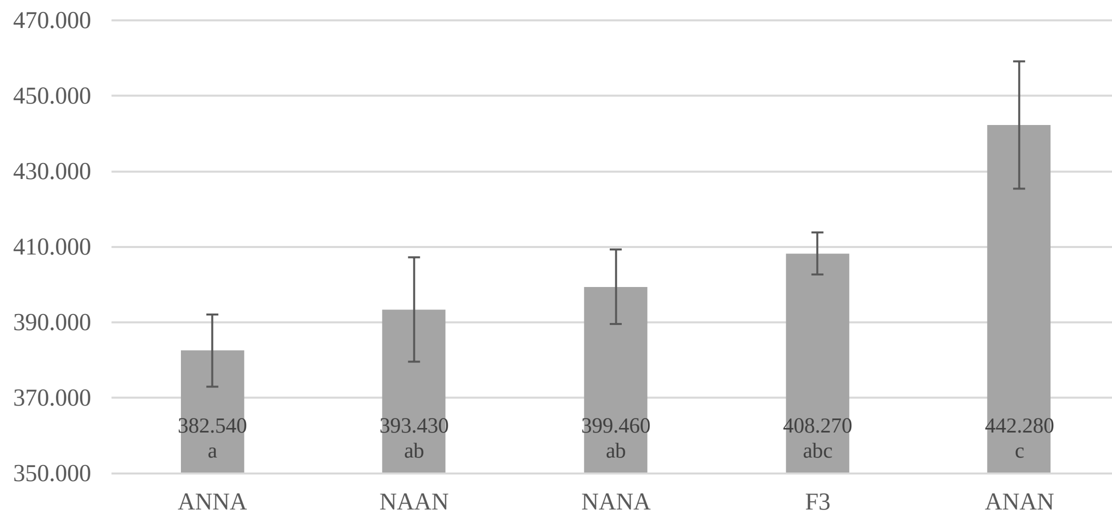


Figure 2. Marbling score least squares means relative to calf type. (Labels on x-axis denote breed makeup of calves, with the first two letters denoting the sire's breeding, and the second two denoted the dam's. F_3 calves were made by crossing F_2 NANA animals. Least squares means with different letters are different at $P < 0.05$.)

Differences in marbling were observed when comparing calf types to one another. Across these calf types, ANAN steers were different from NANA, NAAN, and ANNA steers ($P = 0.028$, 0.025 and 0.002, respectively), having a 42.8, 48.9, and 59.7 more marbling score units, respectively. The ANAN steers also showed a trend of having differences from F_3 steers ($P = 0.055$), with 34.0 more marbling score units on average. Similarly, ANNA calves were found have differences in marbling from F_3 calves ($P = 0.021$), with 25.7 lower marbling score units, but was not found to be different from NANA, or NAAN calves, with NAAN calves also not showing differences from NANA calves. It is of interest to note that calf type did not affect hot carcass weight, adjusted fat thickness, or longissimus muscle area.

An interaction was identified for marbling ($P = 0.017$) between pyrexia status and calf type. Steers exhibiting rectal temperatures greater than 40°C within 14 d following BVDV exposure were classified as exhibiting pyrexia, while steers that were not found to exhibit a rectal temperature greater than 40°C at any time during the study were classified as not exhibiting pyrexia. The least squares means for this interaction are shown in Figure 3.

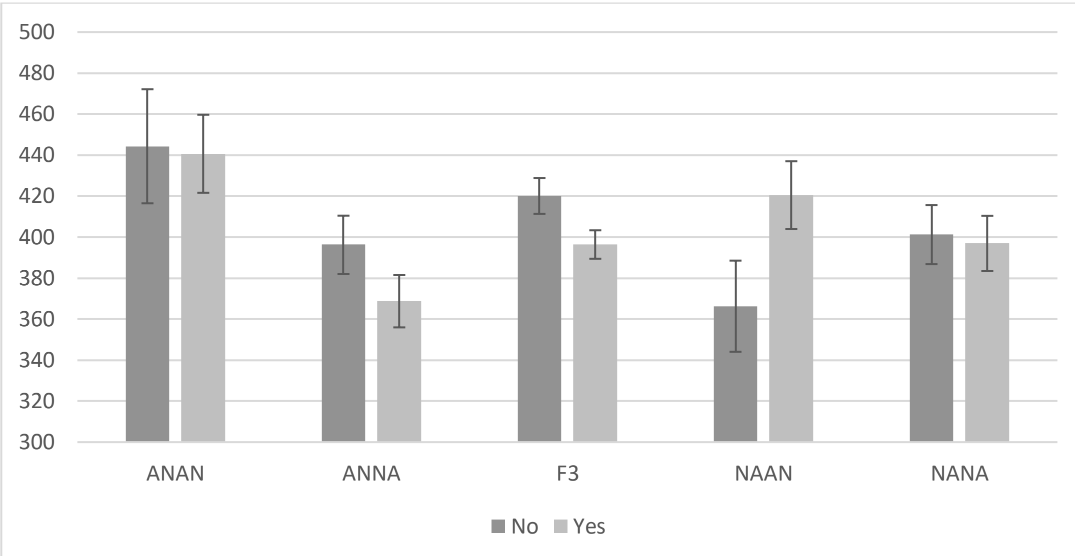


Figure 3. Marbling least squares means relative to presence of pyrexia and calftype. (Pyrexia status was classified on animals presenting rectal temperatures greater than 40°C at any time during the first 14 d following BVDV challenge. Labels on x-axis denote breed makeup of calves, with the first two letters denoting the sire's breeding, and the second two denoted the dam's. F_3 calves were made by crossing F_2 NANA animals.)

This interaction is likely driven by the large difference seen for pyrexia status in NAAN steers, in which case steers not presenting with pyrexia had 54.1 marbling score units less marbling than steers that did present with pyrexia ($P = 0.051$); this goes against the trend seen among other calf types, where there were no differences or slightly higher marbling scores among steers that did not present with pyrexia. Steers that exhibited pyrexia had a tendency ($P = 0.065$) to deposit less intramuscular fat than steers that did not exhibit pyrexia when feed intake ranking was included in the model. A frequency table describing the distribution of calf type by pyrexia status can be seen below in Table 17. The distribution of pyrexia status was not different across calf type based on Chi-square test

Table 17. Frequency distribution of calf type by pyrexia status

Pyrexia[1]	ANAN	ANNA	NAAN	NANA	F_3	Total
Yes	15	33	20	31	115	214
	0.070	0.154	0.093	0.145	0.537	0.601
No	7	27	11	26	71	142
	0.049	0.190	0.077	0.183	0.500	0.399
Total	22	60	31	57	186	356

[1]Pyrexia status was determined by steer presenting rectal temperature > 40° C at any time. Labels across the top denote breed makeup of calves, with the first two letters denoting the sire's breeding, and the second two denoted the dam's. F_3 calves were made by crossing F_2 NANA animals.

Longissimus Muscle Area

Differences in longissimus muscle area were observed due to presence of mild clinical symptoms (P = 0.005). Least squares means for these categories are shown below in Figure 4.

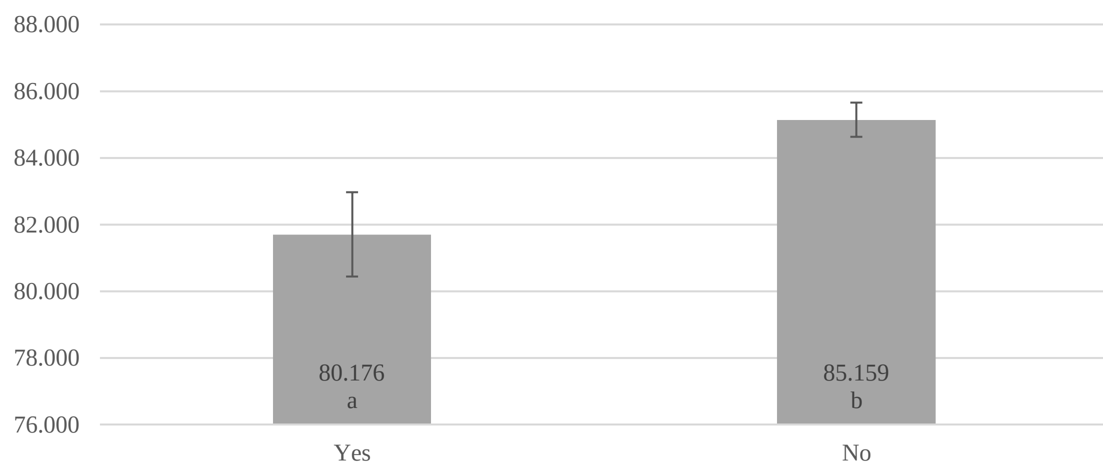
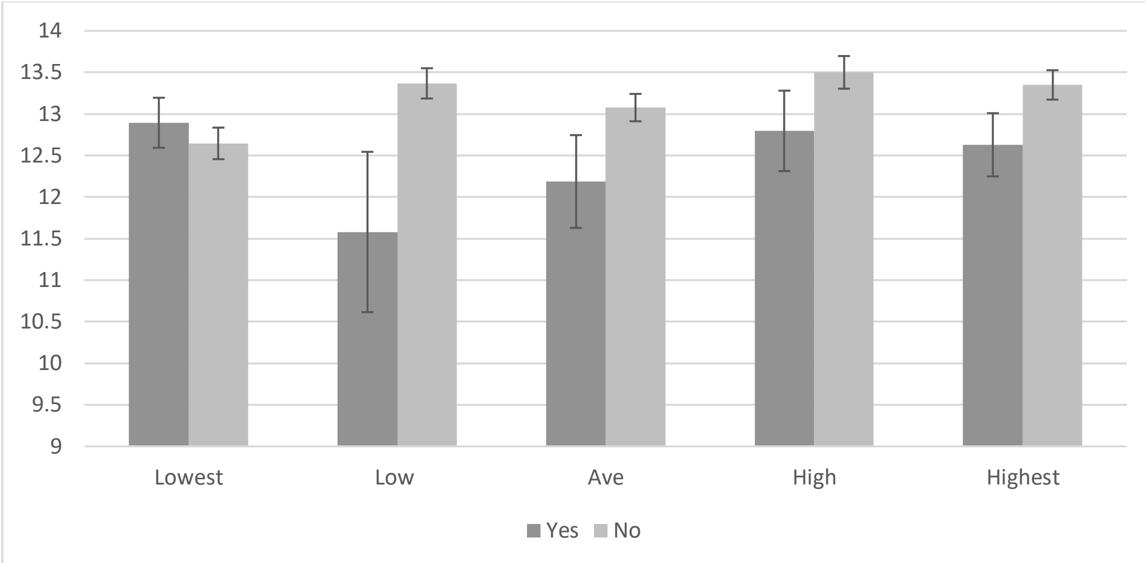


Figure 4. Longissimus muscle area in cm^2 relative to presence of mild clinical symptoms during the 14d following BVDV challenge 150 to 180d prior to harvest. (No = no sign of morbidity, Yes = any sign of morbidity. Animals were evaluated twice per day by the same evaluator across all years. Only minor morbidity signs were documented, classified as scores of 1 or 2 on a 1- to-5 scale for depression, ocular/nasal discharge, coughing, diarrhea, or gauntness.)

Differences in longissimus muscle area were found (*P* = 0.005), with steers exhibiting mild clinical symptoms typical of BRD infection, with steers not showing clinical symptoms having 4.98 cm^2 greater longissimus muscle area.. While no animals presented clinical symptoms severe enough to warrant removal from pen for potential therapeutic treatment, these findings are consistent with Wilson et al. (2017), who found a linear relationship between loin muscle area (LMA) and number of antimicrobial treatments associated with BRD symptoms, with animals having 91.8 cm^2 93.9cm^2, 90.8cm^2, and 87.3cm^2 loin muscle area after being treated zero times, once, twice, or three/four times, respectively (*P* = 0.05).

An interaction was found for longissimus muscle area (*P* = 0.035) involving the presence of clinical symptoms and average daily gain level. Least squares means for this interaction are shown in Figure 5.



No:	57	61	74	53	64
Yes:	21	2	6	8	13

Figure 5. Longissimus muscle area in cm^2 relative to the interaction of average daily gain level immediately following BVDV exposure and clinical symptoms. (Numbers beneath the legend indicate animal counts within the rankings by presence or absence of clinical symptoms. Average daily gain rankings of "Low" and "Highest" differ (P < 0.10). No = no sign of morbidity, Yes = any sign of morbidity. Animals were evaluated twice per day by the same evaluator across all years. Only minor morbidity signs were documented, classified as scores of 1 or 2 on a 1- to-5 scale for depression, ocular/nasal discharge, coughing, diarrhea, or gauntness.)

While not significant at the 0.05 level, a trend has been shown to occur within least squares means for the "low" and "highest" average daily gain rankings (P = 0.070, 0.062), with steers not presenting clinical symptoms having 7.5 and 5.6 cm^2 greater LMA respectively, than steers that did not to interact with the presence of clinical signs for LMA, which is likely being driven by low animal counts and large standard errors within these rankings, with only 2 and 13 animals presenting with mild clinical symptoms in the "low" and "highest" categories, respectively.

Adjusted Fat Thickness

Differences in adjusted fat thickness were found ($P = 0.016$) for vaccine type. Steers receiving MLV treatment had 0.26 cm lower adjusted fat thickness than those receiving KV treatment, but did not differ from steers in the non-vaccinated group. These least squares means are shown in Figure 6.

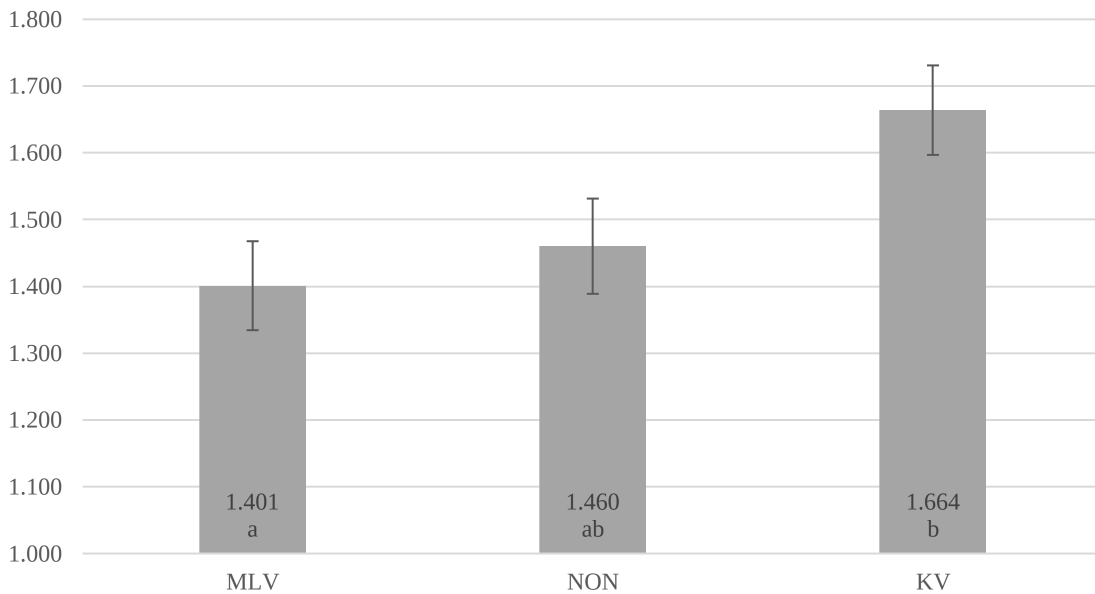


Figure 6. Adjusted fat thickness least squares means relative to vaccine treatment. (Least squares means with different letters are different at $P < 0.05$.)

While differences due to vaccine type were found for adjusted fat thickness, an interaction trend was identified between calf type and vaccine type ($P = 0.069$). Although vaccine treatments were assigned within individual sires, this effect may be driven, at least in part, by low animal counts in some calf types; F_3 calves represented approximately half of all animals in this project. Frequency distributions of vaccine type and calf type are shown in Table 18. Our findings that clinical symptoms were not a significant contributor to adjusted fat thickness is in contrast to Roeber et al. (2001), who found that identification of clinical symptoms in individual animals severe enough to warrant removal to hospital pens two or more times during the feeding period caused adjusted fat thickness to decrease 0.17 cm when compared to animals who were not identified to potential therapeutic treatment. However, it is likely this may be due to the classification of animals in our study, of which, none were identified as having clinical symptoms severe enough to warrant removal from the pen for possible therapeutic treatment as only mild clinical symptoms were documented, and these were only in 14% of animals. It is not clear why vaccine differences would exist for adjusted fat thickness but not carcass weight or marbling score.

Table 18. Frequency distribution of vaccine treatment by calf type.

	ANAN	ANNA	F_3	NAAN	NANA	Total
KV	8	21	59	10	20	118
	0.068	0.178	0.500	0.085	0.169	1.000
MLV	8	21	64	10	10	123
	0.065	0.171	0.520	0.081	0.081	1.000
NON	6	18	63	11	17	115
	0.052	0.157	0.548	0.096	0.148	1.000
Total	22	60	186	31	47	356
	0.062	0.169	0.522	0.087	0.132	1.000

Whole numbers represent animal counts, while decimals below represent percent of animals within that row. Labels across the top denote breed makeup of calves, with the first two letters denoting the sire's breeding, and the second two denoted the dam's. F_3 calves were made by crossing F_2 NANA animals. KV = Killed Virus vaccine, MLV = Modified-Live Virus vaccine, NON = Control animals, not receiving vaccine treatment.

SUMMARY

The objectives of this study were to evaluate differences in traditional carcass traits based on bovine respiratory disease vaccination protocol and health responses in the first 14 days following bovine viral diarrhea virus (BVDV) type 1b challenge, and to investigate calf background effects of sire, type of cross, pyrexia status, presentation of clinical symptoms, temperament, and any interactions of health responses. The results of this study support these objectives, and have brought greater insight to the relationships between events occurring early in the feeding period when animals can be exposed to pathogens, as well as individual animal background information, and how these influences may impact beef carcass merit.

Although 60.5% of the animals in this study presented with pyrexia (> 40.0° C) in the 14 d following BVDV exposure, this factor alone did not explain differences in carcass merit 150 to 180 days later after finishing. Additionally, 13.8% of the animals presented any clinical signs of morbidity, and these signs were not severe enough to warrant potential therapeutic treatment; however presence of these mild clinical symptoms accounted for significant differences in longissimus muscle area.

This study showed that vaccine influenced adjusted fat thickness ($P = 0.016$); modified live virus steers had 0.26 cm lower adjusted fat thickness than killed virus steers, yet did not affect other carcass traits. Marbling was affected by type of cross ($P = 0.023$) with up to 0.60 marbling scores higher ($P < 0.05$) in some parental combinations; an interaction between type of cross and pyrexia status also affected marbling ($P = 0.017$), with one parental combination having higher marbling associated with pyrexia; calf type did not explain variation in other carcass traits. Hot carcass weight was not

affected by pyrexia, but was affected by feed intake during the 14 d period following BVDV challenge ($P = 0.019$), with steers in the highest vs. lowest category averaging 24.0kg heavier, although no animals presented morbidity symptoms severe enough to warrant potential therapeutic treatment, yet presence of mild clinical symptoms affected ribeye area ($P = 0.005$), resulting in 4.98 cm^2 lower ribeye area, but this pattern was inconsistent among feed intake levels.

This study affirms the complexity of health impacts on beef carcass traits and the need for improved study of subclinical illness in beef production systems. While the results from this study have increased the knowledge base of the bovine respiratory disease complex and bovine viral diarrhea, further research is warranted on potential variation in marbling caused by type of cross and a standardized system of diagnosing and describing subclinical illness across animal types and herds.

LITERATURE CITED

Alexenko, A.P., A.D. Ealy, and R.M. Roberts. 1999. The cross-species antiviral activities of different ifn-tau subtypes on bovine, murine, and human cells: contradictory evidence for therapeutic potential. J. Interferon Cytokine Res. 19:1335-1341. doi:10.1089/107999099312795

American Angus Association. 2019. “Angus Genetic Trend by Birth Year”. Retrieved from https://www.angus.org/Nce/GeneticTrends.aspx (Accessed April 15, 2019).

APHIS 2018. Bovine Viral Diarrhea Virus. (2007). Retrieved from https://www.aphis.usda.gov/animal_health/emergingissues/downloads/bvdinfosheet.pdf (Accessed December 1, 2018).

Baker, J. C. 1995. The clinical manifestations of bovine viral diarrhea infection. Vet. Clin. North Am. Food Anim. Pract. 11:425–445.

Bates, K. E., R.L. Weaber, J.M Bormann, D.W. Moser, J.L. Salak-Johnson, C.C. Chase, R.K. Peel, H. V. Campen, G. H. Loneragan, and J. J. Wagner. 2014. Temperament can be an indicator of feedlot performance and carcass merit in beef cattle. Kansas Agricultural Experiment Station Research Reports:34–38.

BIF. 2018. *Guidelines for Uniform Beef Improvement Programs*. 9th Rev. Ed. Beef Improvement Federation,Prairie, MS. https://beefimprovement.org/library-2/bif-guidelines (Accessed 1 December 2018.)

Bolin, S.R. 1995. The pathogenesis of mucosal disease. Vet. Clin. North Am. Food Anim. Pract. 11:3 489-500. doi:10.1016/S0749-0720(15)30463-1

Booker, C.W., S.M. Abutarbush, P.S. Morley, P.T. Guichon, B.K. Wildman, G.K. Jim, O.C. Schunicht, T.J. Pittman, T. Perrett, J.A. Ellis, G. Appleyard, and D.M. Haines. 2008. The effect of bovine viral diarrhea virus infections on health and performance of feedlot cattle. Can. Vet. J. 49:253-260.

Brodersen, B.W. 2014. Manifestations of infection and recent advances in understanding pathogenesis and control. Vet. Pathol. 51: 453-464.

Bryant, T.C., K.C. Rogers, N.D. Stone, and D.G. Miles. 2008. Effect of Viral Respiratory Vaccine Treatment on Performance, Health, and Carcass Traits of Auction-origin Feeder steers. Bov. Prac. 42:1 98-103.

Bunning, H., E. Wall, M.G. Chagunda, G. Banos, and G. Simm. 2018. Heterosis in cattle crossbreeding schemes in tropical regions: meta-analysis of effects on breed combination, trait type, and climate on level of heterosis. J. Anim. Sci. 97:1 29-34. doi:10.1093/jas/sky406

Cooke, R. F. 2014. BILL E. KUNKLE INTERDISCIPLINARY BEEF SYMPOSIUM: Temperament and acclimation to human handling influence growth, health, and reproductive responses in *Bos taurus* and *Bos indicus* cattle. J. Anim. Sci. 92:5325–5333.

Curley, K. O., Jr., D. A. Neuendorff, A. W. Lewis, J. J. Cleere, T. H. Welsh, Jr. and R. D. Randel. 2007. Functional characteristics of the bovine hypothalamic-pituitary-adrenal axis vary with temperament. Horm. Behav. 53:20–27.

Da Silva, A. G., J. A. Musgrave, J. Nollette, A. Applegarth, and R. N. Funston. 2016. Effect of Dam Age on Offspring Productivity. Nebraska Beef Cattle Report:19–21.

Downey-Slinker, E.D., J.F. Ridpath, J.E. Sawyer, L.C. Skow, and A.D. Herring. 2016. Antibody titers to vaccination are not predictive of level of protection against a BVDV type 1b challenge in *Bos indicus – Bos taurus* steers. Vaccine. 34:5053-5059.

Fang, X., E. Downey, C.A. Runyan, J.E. Sawyer, T.B Hairgrove, J.F. Ridpath, C.A. Gill, W. Mwangi, and A.D. Herring. 2012. Correlations of Temperament with Titer and Hematological Responses of Crossbred Steers Challenged with Bovine Viral Diarrhea Virus. J. Anim. Sci. 90(Suppl. 3): 223(Abstr.).

Fell, L.R., I.G Colditz, K.H. Walker, and D.L. Watson. 1999. Associations between temperament, performance and immune function in cattle entering a commercial feedlot. Aust. J. Exp. Agr. 39:795-802.

Fordyce, G., M. Goddard, R. Tyler, G. Williams, and M. Toleman. 1985. Temperament and bruising of *Bos indicus* cross cattle. Aust. J. Exp. Agr. 25:283-288.

Fulton, R.W., J.F. Ridpath, J.T. Saliki, R.E. Briggs, A.W. Confer, L.J. Burge, C.W. Purdy, R.W. Loan, G.C. Duff, and M.E. Payton. 2002. Bovine viral diarrhea virus (BVDV) 1b: predominant BVDV subtype in calves with respiratory disease. Can. J. Vet. Res. 66:3 181-190.

Garcia, M.D., R.M. Thallman, T.L. Wheeler, S.D. Shackelford, and E. Casas. 2010. Effect of bovine respiratory disease and overall pathogenic disease incidence on carcass traits. J. Anim. Sci. 88:491-496. doi:10.2527/jas.2009-1874

Gardner, B. A., H. G. Dolezal, L. K. Bryant, F. N. Owens, and R. A. Smith. 1999. Health of finishing steers: effects on performance, carcass traits, and meat tenderness. J. Anim. Sci. 77:3168-3175.

Gaspers, J.J., K.C. Swanson, F.E. Doscher, M. Rodenhuis, and G.L. Stokka. 2015. Evaluation of response to vaccination on the feedlot performance of weaned calves. North Dakota Beef Report. 25-29

Grandin, T., and C. Shivley. 2015. How farm animals react and perceive stressful situations such as handling, restraint, and transport. Animals 5:1233–1251.

Grandinson, K. 2005. Genetic background of maternal behavior and its relation to offspring survival. Livest. Prod. Sci. 93:43–50.

Griffin, D. 2014. The monster we don't see: Subclinical BRD in beef cattle. Anim. Health Res. Rev. 15:2 138-141. doi:10.1017/S1466252314000255

Griffin, D. 1997. Economic impact associated with respiratory disease in beef cattle. Vet. Clin. North Am. Food Anim. Pract.13:367–377.

Hilton, W.M. 2014. BRD in 2014: Where have we been, where are we now, and where do we want to go? Anim. Health. Res. Rev. 15:120-122.

Holland, B.P., L.O. Burciaga-Robles, D.L. VanOverbeke, J.N. Shook, D.L. Step, C.J. Richards, and C.R. Krehbiel. 2010. Effect of bovine respiratory disease during preconditioning on subsequent feedlot performance, carcass characteristics, and beef attributes. J. Anim. Sci. 88:2486-2499. doi:10.2527/jas.2009-2428

Kayser, W., and R.A. Hill. 2013. Relationship between feed intake, feeding behaviors, performance, and ultrasound carcass measurements in growing purebred Angus and Hereford bulls. J. Anim. Sci. 91:11 5492-5499. doi: 10.2527/jas.2013-6611

Le Neindre, P., L. Grignard, G. Trillat, A. Boissy, F. Ménissier, F. Sapa, and X. Boivin, 2002. Docile limousin cows are not poor mothers. Proc. of the 7th WCGALP, Montpellier, France. CD- ROM communication no. 14-13.

Loneragan, G.H., D.A. Dargatz, P.S. Morley, and M.A. Smith. 2001. Trends in mortality ratios among cattle in US feedlots. J. Am. Vet. Med. Assoc. 219:1122-1127. doi:10.2460/jafma.2001.219.1122

McNeil, J. 1999. Value added calves. Extension Animal Science, Texas A&M. Retrieved from http://aglifesciences.tamu.edu/animalscience/wp-content/uploads/sites/14/2012/04/beef-r2r-4yrsummary.pdf (Accessed March 19, 2018

McVeigh, J.M., P.V. Tarrant, and M.G. Harrington. 1982. Behavioral stress and skeletal muscle glycogen metabolism in young bulls. J. Anim. Sci. 54:790-795. doi:10.2527/jas1982.544790x

Miles, D.G. 2009. Overview of the North American beef cattle industry and the incidence of bovine respiratory disease (BRD). Anim. Health Res. Rev. 10:2 101-103. doi:10.1017.S1466252309990090

Miller, L.L., P.B. Siegel, and E.A. Dunnington. 1992. Inheritance of antibody response to sheep erythrocytes in lines of chickens divergently selected for 56-day body weight and their crosses. Poultry Sci. 71:47-52.

Muggli, N.E., W.D. Hohenboken, L.V. Cundiff, and K.W. Kelley. 1984 Inheritance of maternal immunoglobulin G1 concentration by the bovine neonate. J. Anim. Sci. 59:1 39-48. doi: https://doi.org/10.2527/jas1984.59139x

Neibergs, H.L., J.S. Neibergs, A.J. Wojtowicz, J.F. Taylor, C.M. Seabury, and J.E. Womack. 2014. Economic benefits of using genetic selection to reduce the prevalence of Bovine Respiratory Disease Complex in beef feedlot cattle. Proc. 2014 46th Beef Improvement Federation Annual Meeting and Research Symposium, Lincoln, NE.:82-86. https://beefimprovement.org/wp-content/uploads/2015/08/2014-BIF-Proceedings.pdf (Accessed 18 July 2018).

Olson, C.A., G.E. Carstens, A.D. Herring, D.S. Hale, W.C. Kayser, and R.K. Miller. 2019. Effects of temperament at feedlot arrival and breed type on growth efficiency, feeding behavior, and carcass value in finishing heifers. J. Anim. Sci. 97:4 1828-1839. doi: https://doi.org/10.1093/jas/skz029

Peterhans, E., T.W. Jungi, and M. Schweizer. 2003. BVD and innate immunity. Biologicals. 31:107-111.

Reinhardt, C., M. Hands, T. Marston, J. Waggoner, and L. Corah. 2012. Relationships between feedlot health, average daily gain, and carcass traits of Angus steers. PAS 28:11–19.

Reinhardt, C.D., W.D. Busby, and L.R. Corah. 2009. Relationship of various incoming cattle traits with feedlot performance and carcass traits. J. Anim. Sci. 87:3030-3042. doi:10.2527/jas2008-1293

Ridpath, J. F. 2013. Immunology of BVDV vaccines. Biologicals 41:14-19.

Ridpath, J. F., P. Dominowski, R. Mannan, R. Yancey, J. A. Jackson, L. Taylor, S. Mediratta, R. Eversole, C. D. Mackenzie, and J. D. Neill. 2010. Evaluation of three experimental bovine viral diarrhea virus killed vaccines adjuvanted with combinations of Quil A cholesterol and dimethyldioctadecylammonium (DDA) bromide. Veterinary Research Communications 34:691–702.

Ridpath, J.F., J.D. Neill, and E. Peterhans. 2007. Impact of variation in acute virulence of BVD1 strains on design of better vaccine efficacy challenge models. Vaccine. 25:8058-8066.

Riley, D.G., C.A. Gill, A.D. Herring, P.K. Riggs, J.E. Sawyer, D.K. Lunt, and J.O. Sanders. 2014. Genetic evaluation of aspects of temperament in Nellore-Angus calves. J. Anim. Sci. 92:8 3223-3230. doi: 10.2527/jas.2014-7797

Roeber, D.L., N.C. Speer, J.G. Gentry, J.D. Tatum, C.D. Smith, J.C. Whittier, G.F. Jones, K.E. Belk, and G.C. Smith. 2001. Feeder cattle health management: Effects on morbidity rates, feedlot performance, carcass characteristics, and beef palatability. Prof. Anim. Sci. 17:39-44.

Runyan, C.A., E.D. Downey-Slinker, J.F. Ridpath, T.B. Hairgrove, J.E. Sawyer, and A.D. Herring. 2017. Feed intake and weight changes in *Bos indicus-Bos taurus* crossbred steers following Bovine Viral Diarrhea Virus Type 1b challenge under production conditions. Pathogens. 6:4 66. doi:10.3390/pathogens6040066

Runyan, C.A., X. Fang, E.D. Downey, J.E. Sawyer, T.B. Hairgrove, J.F. Ridpath, and A.D. Herring. 2014. Evaluation of weight gain and rectal temperature across vaccine type in *Bos indicus* crossbred steers challenged with Bovine Viral Diarrhea virus. J. Anim. Sci. (Suppl. 1, Southern Section ASAS page 32).

Schneider, M.J., R.G. Tait Jr., W.D. Busby, and J.M. Reecy. 2009. An evaluation of bovine respiratory disease complex in feedlot cattle: Impact on performance and carcass traits using treatment records and lung lesion scores. J. Anim. Sci. 87:1821-1827. doi:10.2527/jas.2008-1283

Schunicht, O.C., C.W. Booker, G.K. Jim, P.T. Guichon, B.K. Wildman, and B.W. Hill. 2003. Comparison of a multivalent viral vaccine program versus a univalent viral vaccine program on animal health, feedlot performance, and carcass characteristics of feedlot calves. Can. Vet. J. 44:43-50.

Snowder, G.D.; L.D. Van Vleck. L.V. Cundiff, and G.L. Bennett. 2005. Influence of breed, heterozygosity, and disease incidence on estimates of variance components of respiratory disease in preweaned beef calves. J. Anim. Sci. 83:1247-1261.v doi:10.2527/2005.8361247x

Snowder, G. D., L.D. Van Vleck, L.V. Cundiff, and G.L. Bennett. 2006. Bovine respiratory disease in feedlot cattle: Environmental, genetic, and economic factors. J. Anim. Sci. 84:1999–2008.

Smith, P.S., G.E. Carstens, C.A. Runyan, J.F. Ridpath, J.E. Sawyer, and A.D. Herring. 2017. 085 Effects of vaccine treatment and temperament classification on intake and feeding behavior responses to bovine viral diarrhea virus challenge in beef steers. J. Anim. Sci. 94:42. doi:10.2527/asasann.2017.085

Smith, R.A. 1998. Impact of disease on feedlot performance: A review. J. Anim. Sci. 76:272-274.

Sowell, B. F., M.E. Branine, J.G.P. Bowman, M.E. Hubbert, H.E. Sherwood, and W. Quimby. 1999. Feeding and watering behavior of healthy and morbid steers in a commercial feedlot. J. Anim. Sci. 77:1105-1112. doi:10.2527/1999.7751105x

Theurer, M.E., R.L. Larson, and B.J. White. 2015. Systematic review and meta-analysis of the effectiveness of commercially available vaccines against bovine herpesvirus, bovine viral diarrhea virus, bovine respiratory syncytial virus, and parainfluenza type 3 virus for mitigation of bovine respiratory disease complex in cattle. J. Am. Vet. Med. Assoc. 246:1 126-142. doi: 10.2460/javma.246.1.126.

Thompson, P, A. Stone, and W. Schultheiss. 2006. Use of treatment records and lung lesion scoring to estimate the effect of respiratory disease on growth during early and late finishing periods in South African feedlot cattle. J. Anim. Sci. 84:488-498.

USDA, 2011. Feedlot 2011 Part IV: Health and health management on U.S. feedlots with a capacity of 1,000 or more head. USDA-APHIS-VS-CEH- NAHMS. Fort Collins, CO #638.0913

Van der Most, P.J., J.D. Berber, H.K. Parmentier, and S. Verhlust. 2010. Trade-off between growth and immune function: a meta-analysis of selection experiments. Fun. Ecology. 25:1 74-80. doi:10.1111/j.1365-2435.2010.01800.x

Waggoner, J W, C.P. Mathis, C.A. Löest, J.E. Sawyer, F.T. McCollum III, and J.P. Banta. 2007. Impact of morbidity in finishing beef steers on feedlot average daily gain, carcass characteristics, and carcass value. PAS. 23:2 174-178. doi:10.15232/S1080-7446(15)30958-X

Wilson, B.K., PAS, D.L. Step, C.L. Maxwell, C.A. Gifford, C.J. Richards, and C.R. Krehlbiel. 2017. Effect of bovine respiratory disease during the receiving period on steer finishing performance, efficiency, carcass characteristics, and lung scores. Prof. Anim. Sci. 33:24-36. doi:10.15232/pas.2016-01554

Wittum, T. E., N. E. Woollen, L. J. Perino, and E. T. Littledike. 1996. Relationships among treatment for respiratory tract disease, pulmonary lesions evident at slaughter and rate of weight gain in feedlot cattle. J. Am. Vet. Med. Assoc. 209:814–818.

Wittum, T. E., and L. J. Perino. 1995. Passive immune status at postpartum hour 24 and long-term health and performance of calves. Am. J. of Vet. Res. 56:1149–1154.

Zoetis 2018. Bovine Viral Diarrhea Virus Type 1 and Type 2 (BVD). (2018). Retrieved from https://www.zoetisus.com/conditions/beef/bovine-viral-diarrhea-virus-type-1-and-type-2-_bvd_.aspx (Accessed September 15, 2018)